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Comparison of the metabolism of two floodplain lakes of the Trombetas River (Pará, Brazil) based on a study of diel variation

by

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Abstract

The diel variation of temperature, pH, electrical conductivity, dissolved oxygen concentration and chlorophyll-a was investigated in Batata and Mussurá Lakes on the Trombetas River floodplain. The diel variation of temperature was distinct in both lakes. The water column of Batata lake was completely mixed after $22^{\underline{00}}$ hour and Mussurá lake developed a well stablished gradient of temperature (differences up to 5.6 °C between surface and depth) which persisted all over the period studied. The thermal behavior determined the diel variation of the other parameters studied, which presented a homogenous vertical distribution in Batata Lake and remained stratified in Mussurá Lake. Chlorophyll-a concentrations were considerably lower in Batata Lake (1.8 µg/l) than in Mussurá Lake (10.8 µg/l) and resulted in production values (measured by oxygen diel variation) of ca. 2.6 g $O_2 \cdot m^{-2} \cdot d^{-1}$ in the first and 18.2 g $O_2 \cdot m^{-2} \cdot d^{-1}$ in the former one.

Keywords: **Amazonian lakes, diel variation, lake metabolism.**

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Introduction

The analyses of the diel dynamic of limnological parameters has been considered very important to understand the ecology of tropical lakes. TALLING (1957) and ESTEVES et al. (1988) have noted that the amplitudes of variation of ecological processes in tropical lakes may be greater over a 24-hour (diel) period than over the period of a year (seasonal). This has also been demonstrated by other authors. MacINTYRE & MELACK (1988) studied the diel variations of some abiotic factors in Amazonian lakes and BARBOSA & TUNDISI (1989) studied diurnal variation in water temperature and its influence on the distribution of dissolved nutrients, in Carioca Lake (State of Minas Gerais).

Batata and Mussurá Lakes are situated in the floodplain of the Trombetas River. They are on opposite banks of the river and differ in their degree of communication with the river, especially during the filling phase. Batata Lake has its main axis parallel to the Trombetas River and is separated from the river by a narrow strip of "restinga" (forest vegetation). The narrowness of the "restinga" facilitates the entrance of river water into the lake and leads to semi lotic characteristics during the filling phase. Mussurá Lake, oriented perpendicularly to the Trombetas, has a smaller area of communication with the river and maintains lentic characteristics, especially during the filling period.

As a consequence of this difference between the hydraulic characteristics of the two lakes during the filling phase, it is of ecological interest to identify the differences in their diel dynamics at this period.

This study aims to contribute to understanding of the diel dynamics of the principal abiotic factors and chlorophyll-a concentrations in Batata and Mussurá Lakes at the end of the filling period, and from these data to infer the nature of the metabolism (production and respiration) of both ecosystems.

Study Area

Batata and Mussurá Lakes are clear-water ecosystems of the "*várzea*" (floodplain) of the Trombetas River, an affluent of the left bank of the Amazon River (Fig. 1). The total area and depth of both lakes change considerably during the year as a function of the Trombetas River water level, which can vary more than 6 meters annually. During filling water phase the areas of Batata and Mussurá Lakes are of ca. 29.5 and 7.7 km^2 respectively, and the depths usually oscilate between 0.5 and 9.0 meters along the year. During the low water period, Batata Lake and Mussurá Lake each has a single point of communication with the Trombetas River. During the high water period Mussurá Lake continues to have a single communication with the river, while Batata Lake is linked to the Trombetas over a large flooded area. Both lakes are surrounded by "*igapó*" (periodically inundated forest) and are little colonized by aquatic macrophytes. In a few parts there are banks of the grass *Oriza perenis* which grows during the low water period.

Beside the morphometric and hydrodynamic differences, Batata Lake differs from Mussurá Lake in having been for 10 years (1979-1989) a locality for deposition of tailings resulting from processing of bauxite ore by the Mineração Rio do Norte SA Company. These tailings impacted about 30 % of the lake area with clays rich in

aluminum oxide, silicates and iron oxide (LAPA & CARDOSO 1988).

Methods

The samplings were carried out on 22-23 June 1991 in Batata Lake and on 26-27 June 1991 in Mussurá Lake, during the period of highest water levels. The sampling stations were located in the deepest part of each lake (8 meters), and in Batata Lake in an area free of the influence of bauxite tailings. Collections were made at 4-h intervals at surface, 1.5, 3.0, 4.5, 6.0 and 7.5 meters. The temperature was measured every 10 cm down to 2.5 m and every 50 cm between 2.5 and the lake bottom.

Water temperature was measured with a FAC 400 electronic thermometer (resolution of 0.1 °C). Immediately after collection the pH and electrical conductivity of the water samples were measured with portable DIGIMED meters. The values of electrical conductivity were corrected to 25 °C. Dissolved oxygen concentrations were obtained by the WINKLER method as modified by GOLTERMAN et al. (1978). Chlorophyll-a concentrations were determined according to GOLTERMAN et al. (1978), after filtering 250 ml water through GF/C filters which were frozen until the determinations were carried out in the laboratory.

Primary production and respiration values were estimated by diurnal monitoring of dissolved oxygen concentrations, not corrected to effusive exchanges, as described by TALLING (1957). The following procedure was used:

(a) duration of illuminated period of the day (h);
(b) maximum increase of dissolved oxygen concentrations during the illuminated period ($g{\cdot}m^{-2}$);
(c) mean rate of nocturnal decrease of dissolved oxygen concentrations ($g\ O_2{\cdot}m^{-2}{\cdot}h^{-1}$);
(d) estimation of losses (principally respiration) of dissolved oxygen during the illuminated period ($g{\cdot}m^{-2}$) = (a) x (c);
(e) estimation of dissolved oxygen production per day ($g\ O_2{\cdot}m^{-2}$) = (b) + (d);
(f) estimation of respiration per day ($g\ O_2{\cdot}m^{-2}$) = (c) x 24 (number of hours per day).

Results

The temperatures obtained in Batata Lake had a diel pattern with thermal gradients great as 3.1 °C. However, homogenization of the water column occurred from $22^{\underline{00}}$ to $2^{\underline{00}}$ hours, when no thermal gradient was observed to a depth of 4 m (Fig. 2).

In Mussurá Lake, strong thermal gradients were measured which persisted during the 24 hours of the study (Fig. 2), and the thermal gradient resulting from heating during the day remained restricted only to the first meter of the water column. The greatest temperature difference between the surface and the deepest layer was 5.6 °C at $12^{\underline{00}}$ hours. Mussurá Lake had two welldefined thermoclines, one of these formed between 1 and 2 m depth and the other between 7 and 8 m (the maximum depth).

The pH values were slightly acid (5.4 to 6.1) in both lakes. In Mussurá Lake, higher pH values were measured in the surface layer between $12^{\underline{00}}$ and $20^{\underline{00}}$ hours, while in Batata Lake, a tendency toward more homogenous vertical distribution of pH values was observed (Fig. 3).

In Batata Lake, a relatively homogenous vertical distribution of electrical conductivity was observed over the diel period, with values lower than 12 $\mu S{\cdot}cm^{-1}$ (Fig. 4). Mussurá Lake remained vertically stratified for the 24-hour study, the highest values being detected in the water layer below a depth of 6.0 m (Fig. 4).

The same patterns of diel variation of dissolved oxygen concentration was observed

in both lakes. An accentuated increase in dissolved oxygen occurred between $12^{\underline{00}}$ and $20^{\underline{00}}$ hours (Fig. 5). This increase occurred even in the deepest layers, where values of 102 % saturation were measured at $18^{\underline{00}}$ hours in Batata Lake and 40 % saturation at $16^{\underline{00}}$ hours in Mussurá Lake.

The lakes differed in the amplitude of spatial and temporal variation of their dissolved oxygen values. While in Batata Lake values between 93 and 118 % saturation were obtained, Mussurá Lake showed values which oscillated between 7 and 136 % saturation (Fig. 5).

Concentrations of chlorophyll-a were higher in Mussurá Lake where an accumulation of phytoplankton biomass (reflected in the concentrations of chlorophyll-a) was observed between $10^{\underline{00}}$ and $18^{\underline{00}}$ hours in the water layer between 1.0 and 3.0 m depth. Between $20^{\underline{00}}$ and $4^{\underline{00}}$ hours, the vertical distribution became more homogeneous (Fig. 6). Batata Lake had low concentrations of chlorophyll-a (<3.5 $mg \cdot l^{-1}$), with nearly a homogeneous distribution during the period analyzed (Fig. 6).

The values obtained for primary production and respiration were different between the two lakes (Tab. 1). While in Batata Lake the value obtained for production was only 2.6 $g\ O_2 \cdot m^{-2} \cdot d^{-1}$ (ca. 0.9 $g\ C \cdot m^{-2} \cdot d^{-1}$), in Mussurá Lake a value was obtained of 18.2 $g\ O_2 \cdot m^{-2} \cdot d^{-1}$ (ca. 6.6 $g\ C \cdot m^{-2} \cdot d^{-1}$).

Discussion

Mussurá and Batata Lakes, although they are located on the same floodplain and are both influenced by the Trombetas River, had distinct diel patterns in the limnological variables analyzed. While Batata Lake became isothermal at the end of the night, Mussurá Lake remained stratified during the entire period. In Batata Lake, the formation of unstable density gradients due to convection currents as was suggested by MacINTYRE & MELACK (1988) for other Amazonian lakes, and the occurrence of winds as was observed at $20^{\underline{00}}$ hours may have contributed to mixing of the water column. Although the current wasn't measured, there are evidences that during the high water period the entrance of water from the Trombetas River can be considered an important factor in homogenizing the water column.

In Mussurá lake, since only one area of communication is maintained with the Trombetas River because of the lake's perpendicular orientation to the river, lentic characteristics persist even during the high water period. This is indicated as the probable responsible factor in the formation of a stable thermocline that also occurs in Mussurá Lake at other periods of the hydrological cycle (BOZELLI & ESTEVES 1991). The persistence of thermal stratification during the high water period was also observed in other *várzea* lakes (MacINTYRE & MELACK 1988; JUNK 1984; THOMAZ 1991).

The distinct diel thermal patterns observed in Batata and Mussurá Lakes determined the diel behavior of the other limnological parameters. The elevation of pH values during the afternoon in the surface waters of Mussurá Lake can be attributed to photosynthetic activity of the phytoplankton, which at this time of day was concentrated between 1 and 3 m depth, as indicated by the results of chlorophyll-a concentration. The variation in pH is facilitated by the low buffering capacity of the water (SILVA 1991). Similar results was also observed by SCHMIDT (1973) in Janauarí Lake and by CAMARGO & MIYAI (1988) in Curuça Lake, also in the Rio Trombetas floodplain.

In Batata Lake the more homogenous vertical distribution of pH values and the lack of a diel patterns of variation like that observed in Mussurá Lake can be attributed to the lower thermal stability of the water column as well as to the smaller phytoplankton biomass.

The greater thermal stability in Mussurá Lake can also be suggested as a factor responsible for the accumulation of ions in the hypolimnion which results from the decomposition of organic matter and from water-sediment exchange. This fact is evidenced by the greater values of electrical conductivity obtained in the deeper layers of Mussurá Lake, which was not observed in Batata Lake.

The high rate of decomposition of organic matter are suggested as the principal factor responsible for the rapid decrease in dissolved oxygen concentration at night and especially near dawn. The dissolved oxygen concentrations measured near the sediment in Mussurá Lake decreased from 40 % saturation (3.12 $mg\ O_2 \cdot l^{-1}$) at $16^{\underline{00}}$ hours to 16 % saturation (1.25 $mg\ O_2 \cdot l^{-1}$) at $4^{\underline{00}}$ hours, which indicaters an approximate consuption of 0.16 $mg\ O_2 \cdot l^{-1} \cdot h^{-1}$ in the hypolimnion of this lake. However, light penetration to the bottom (values between 10 and 25 $m\ mol \cdot m^{-2} \cdot s^{-1}$), principally in Mussurá Lake, permits high rates of photosynthesis even in deeper parts of the lake (data not shown), which reduces the possibility of anoxia. The presence of several species of diatoms, chiefly *Melosira granulata* and *Melosira agassizii* var. *malayensis* in abundance on the sediment should be mentioned. The accumulation of these planktonic species on the bottom may be due to the lower water turbulence in Lake Mussurá, as a function of the thermal stratification. According to PAYNE (1986), under such conditions the diatoms, especially members of the genus *Melosira*, have high sedimentation rates.

The values of oxygen supersaturation observed in both lakes and the marked increment in concentrations of this gas observed during the day, even in the hypolimnion of Mussurá Lake, indicate the important role of phytoplankton photosynthetic activity in adding oxygen to the system. The supersaturation values suggest that both lakes liberate oxygen to the atmosphere, in contrast to the results obtained by MELACK & FISHER (1983) for Calado Lake, where diffusive input from the atmosphere constitutes the principal source of oxygen.

The highest concentrations of dissolved oxygen observed during the daylight period, as well as the large diel oscillation of oxygen values in Mussurá Lake reinforce the importance of phytoplankton production.

The results of the chlorophyll-a concentrations demonstrate accumulation of phytoplankton biomass between $12^{\underline{00}}$ and $20^{\underline{00}}$ hours in the layer between 1 and 3 m depth in Mussurá Lake. During the early daylight hours chlorophyll-a continued to show a certain degree of vertical stratification, although less so than during the afternoon. The heterogeneous vertical distribution of the phytoplankton community can be associated with the greater stability of thermal stratification in this lake than in Batata Lake. In the latter the semi-lotic characteristics afforded by the constant entry of water from the Trombetas River during the high water period did not favor accumulation of phytoplankton biomass nor its vertical structuring in the water column. The pattern of diel variation observed for Mussurá Lake during the high water period was similar to the pattern observed by CAMARGO & MIYAI (1988) during the drawdown period in Curuça Lake, which is located on the same floodplain.

Studies of the diel variation of dissolved oxygen as a basis for estimation of production and respiration of aquatic ecosystems have been proposed by several investigators

(VINBERG & YAROVITZINA 1939; ODUM 1956; TALLING 1957). Mussurá Lake, with chlorophyll-a concentrations 8.3 times higher than in Batata Lake, showed primary production and respiration values 7.0 and 11.6 times higher respectively. The high rates of production and respiration observed in Mussurá Lake, compared to those in Batata Lake, may be due to the different morphometries of the two lakes which in part determine different hydrodynamics in the two environments. The water turbulence associated with the effect of the dilution which occurs during the high water period may be an important factor responsible for the low value of primary production obtained in Batata Lake. In Mussurá Lake the more favorable hydrodynamic conditions during the high water period make possible the intense development of the phytoplankton community. The high rate of respiration obtained in this lake in turn can be related to the high concentrations of autochtonous organic detritus, from the phytoplankton production (FERRÃO FILHO & ESTEVES 1994).

Consequently we can conclude trat Batata and Mussurá Lakes, although located on the same floodplain and influenced by the same river, show considerally different metabolic patterns during the high water periods. These differences are seen in several abiotic variables, and in the amplitude of the variation of important ecological processes of these ecosystems, such as production and respiration.

Summary

The study of temperature, pH, electrical conductiviy, dissolved oxygen and chlorophyll-a in Batata and Mussurá Lakes demonstrated that although these two ecosystems are on the same floodplain (Trombetas River, an affluent of the left bank of the Amazon River, State of Pará), they have different diel patterns of these variables. Only Mussurá Lake remained thermally stratified during the entire diel cycle while Batata Lake became isothermal near the end of the night. The distinct diel thermal patterns determined the behavior of the remaining limnological variables analyzed. Calculations of primary production and respiration from the diel variation of dissolved oxygen showed differences between the two ecosystems. While in Batata Lake the value obtained for production was 2.6 g $O_2 \cdot m^{-2} \cdot d^{-1}$ (ca. 0.9 g $C \cdot m^{-2} \cdot d^{-1}$), in Mussurá Lake the corresponding value was 18.2 g $O_2 \cdot m^{-2} \cdot d^{-1}$ (ca. 6.6 g $C \cdot m^{-2} \cdot d^{-1}$). Values for respiration rates found in Mussurá Lake were 12 times higher than those in Batata Lake. The high degree of differentiation in the metabolism of these ecosystems was attributed to the different morphometries which determined the characteristic hydrodynamics of each lake.

Resumo

A variação nictemeral da temperatura, pH, condutividade elétrica, concentração de oxigênio dissolvido e clorofila-**a** foi pesquisada nos Lagos Batata e Mussurá, ambos da planície de inundação do rio Trombetas. A variação diurna da temperatura foi distinta em ambos os lagos estudados. Mistura completa da coluna d'água do Lago Batata foi observada após as 22 $\underline{00}$ horas e o Lago Mussurá desenvolveu gradientes térmicos bem desenvolvidos (diferenças de até 5.6 °C entre a superfície e o fundo) que persistiram por todo o período analisado. O comportamento térmico determinou a variação diária dos demais parâmetros estudados os quais apresentaram uma distribuição vertical homogênea no Lago Batata e permaneceram estratificados no Lago Mussurá. As concentrações de clorofila-**a** foram consideravelmente menores no Lago Batata (1.8 µg/l) do que no lago Mussurá (10.8 µg/l) e resultaram em valores de produção primária (medidas pela variação diária do oxigênio dissolvido) de aproximadamente 2.6 g $O_2 \cdot m^{-2} \cdot d^{-1}$ no primeiro e 18.2 g $O_2 \cdot m^{-2} \cdot d^{-1}$ no último.

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Table 1: Values of chlorophyll-a and of gross primary production and respiration obtained in Lakes Batata (22-23/June/1991) and Mussurá (26-27/June/1991), estimated from monitoring dissolved oxygen concentrations during 24 hours. Data not corrected to diffusion.

	Batata Lake		**Mussurá Lake**	
	Oxygen	**Carbon**	**Oxygen**	**Carbon**
Primary production ($g \cdot m^{-2} \cdot d^{-1}$)	2.6	0.975	18.2	6.825
Respiration ($g \cdot m^{-2} \cdot d$-1)	1.1	0.412	12.8	4.800
Chlorophyll-**a** ($\mu g \cdot l^{-1}$)	1.8		10.8	

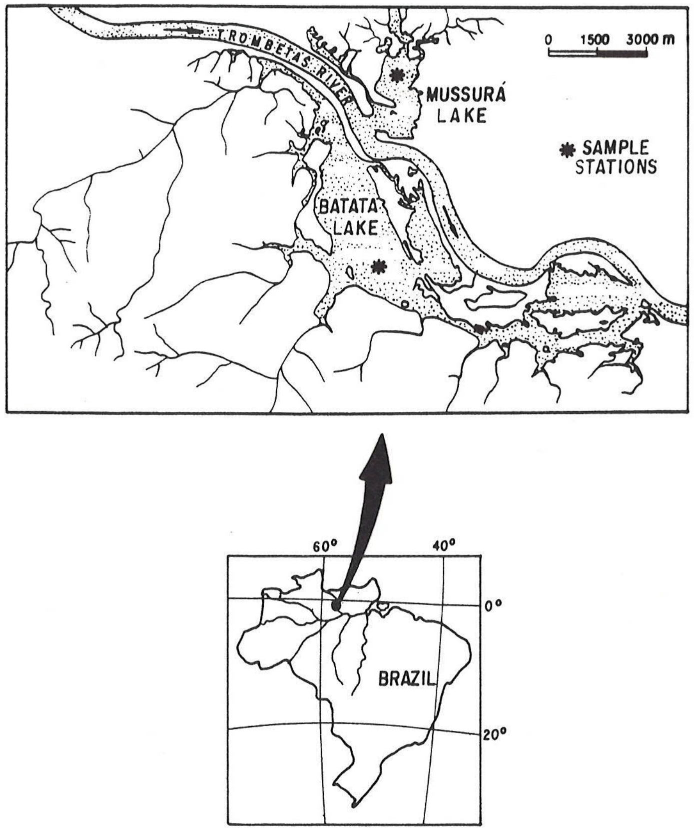

Fig. 1:
Locations of Batata and Mussurá Lakes and the respective sampling stations.

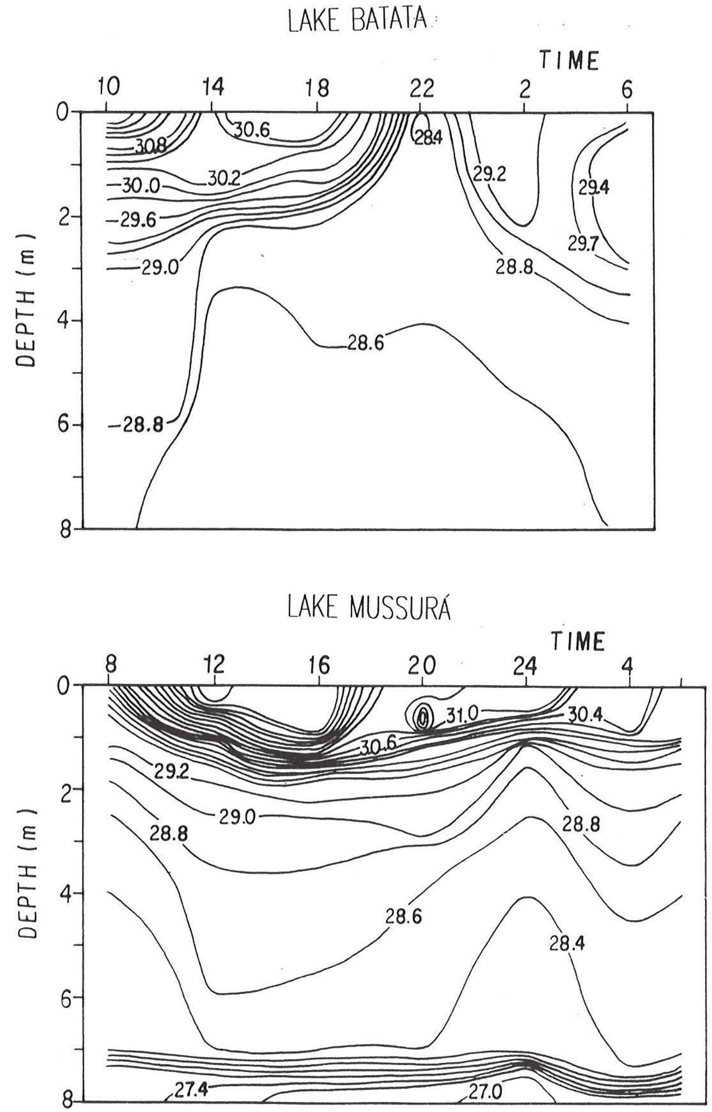

Fig. 2:
Values for diel temperature (°C) in the water column obtained in Batata and Mussurá Lakes.

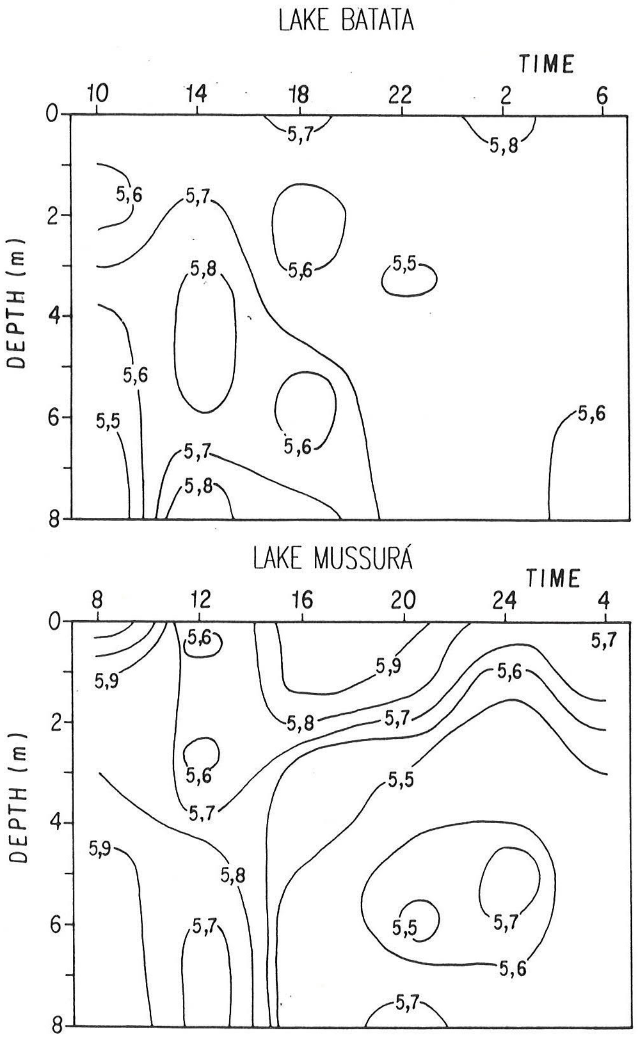

Fig. 3:
Diel pH values obtained in Batata and Mussurá Lakes in relation to depth.

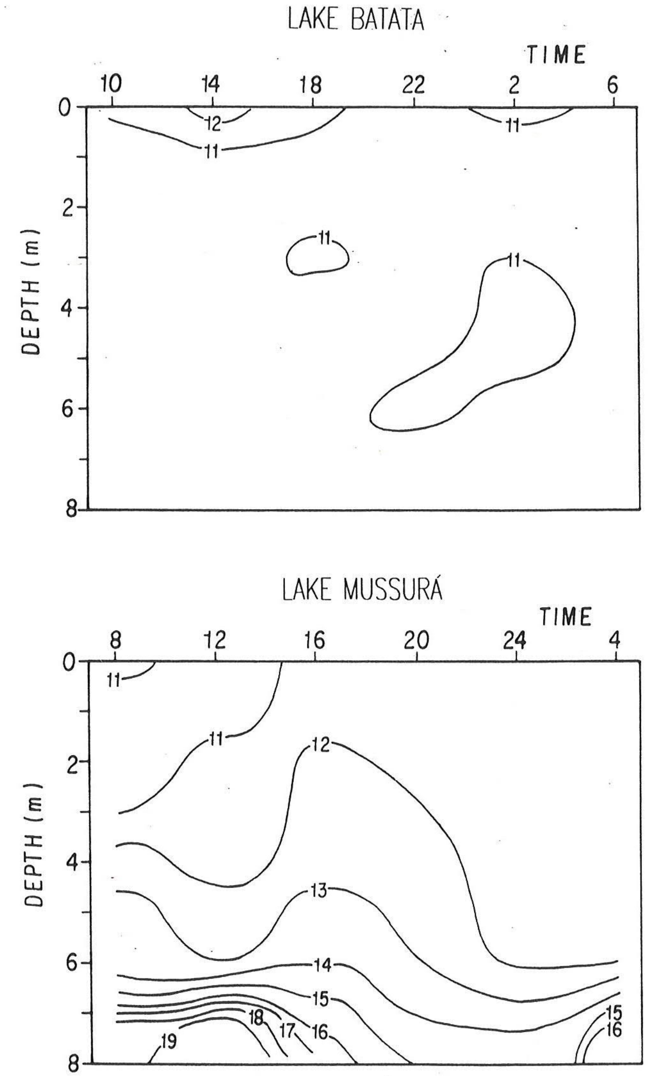

Fig. 4:
Diel values for electrical conductivity ($\mu S \cdot cm^{-1}$; corrected to 25 °C) obtained in Batata and Mussurá Lakes.

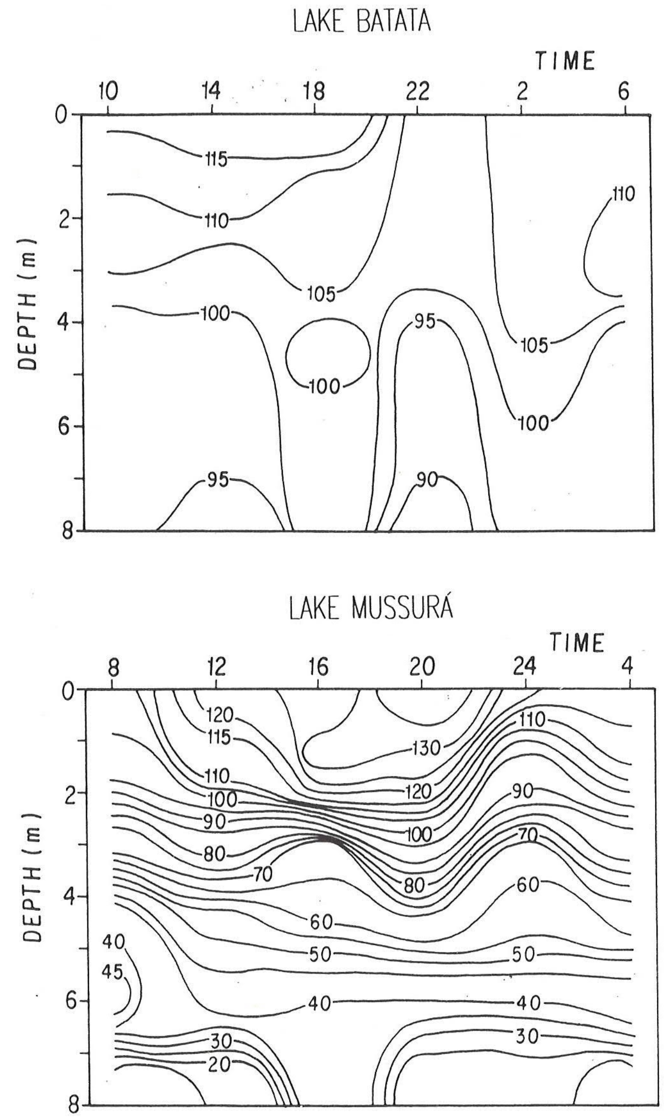

Fig. 5:
Diel variation for dissolved oxygen saturation (% saturation) obtained in Batata and Mussurá Lakes.

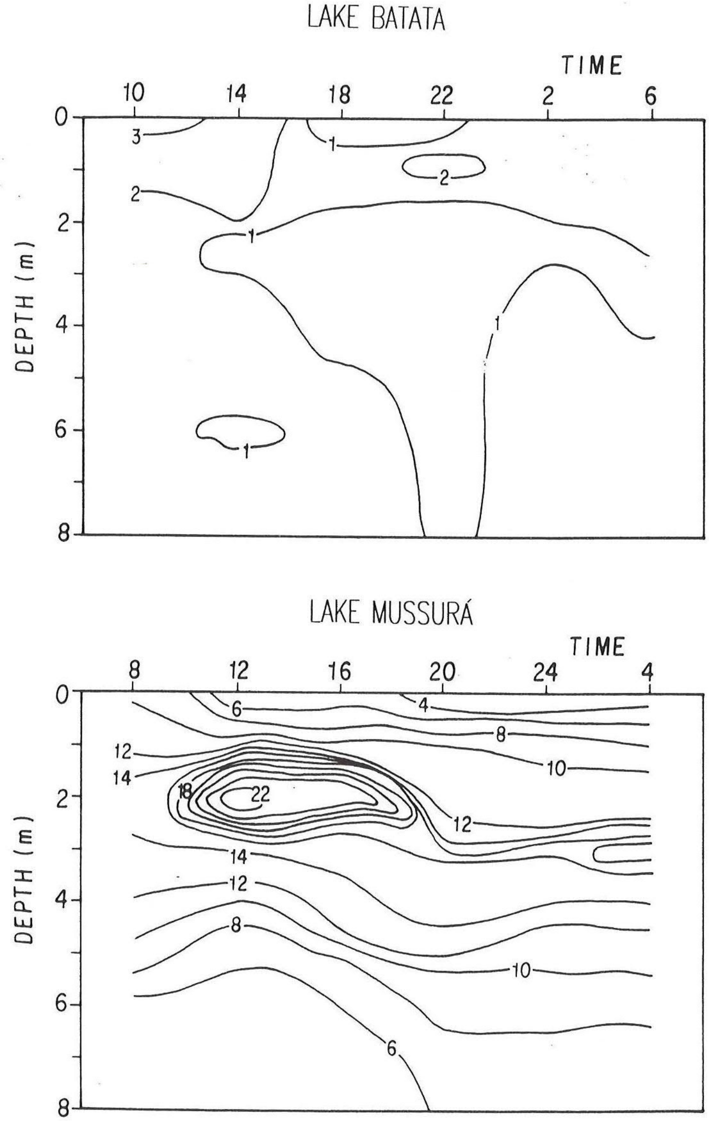

Fig. 6:
Diel variation of chlorophyll-a concentrations ($\mu g \cdot l^{-1}$) obtained in Batata and Mussurá Lakes.